Renewable and Sustainable Energy Reviews 22 (2013) 101–107

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Promote the development of renewable energy: A review and empirical study of wind power in China

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ARTICLE INFO

Article history:
Received 1 July 2012
Received in revised form
21 January 2013
Accepted 23 January 2013
Available online 28 February 2013

Keywords:
Wind power
Policy simulation
Monte Carlo
MCA

ABSTRACT

It is highly significant for China to improve its development of wind power. In order to promote the sustainable development, a more comprehensive evaluation of factors affecting the effectiveness of investment in the industry wind power is required to be conducted to formulate a relatively stable policy supporting mechanism for the development of wind power. Based on the green accounting framework, this paper evaluates a typical wind power project from economic, environment and energy alternative respects comprehensively. We simulate the main factors influencing cost and benefit of the wind power investment with the Monte Carlo method. Finally, we discuss how to promote wind power with respect to the concern of government, investors and environmentalists.

Contents

1. Introduction

The development of renewable energy such as wind power has become one of the strategic choices for many countries that try to build a sustainable energy system and achieve low carbon economies. Due to resource, technology, investment and other constraints, coal still dominates in China's energy consumption structure (shown in Fig. 1). In 2010, coal, oil and natural gas, non-fossil energy consumption accounted for 68%, 19%, 4.4% and 8.6% of the total consumption respectively, while wind energy only makes up a slight proportion of non-fossil energy. In order to achieve the goal that carbon dioxide (CO_2) emission per unit of GDP in 2020 is lower than that of 2005 by 40–45%, it is absolutely urgent for China to develop renewable energy. The studies by Li [1,2] show that wind energy has prominent technical and

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http://dx.doi.org/10.1016/j.rser.2013.01.025

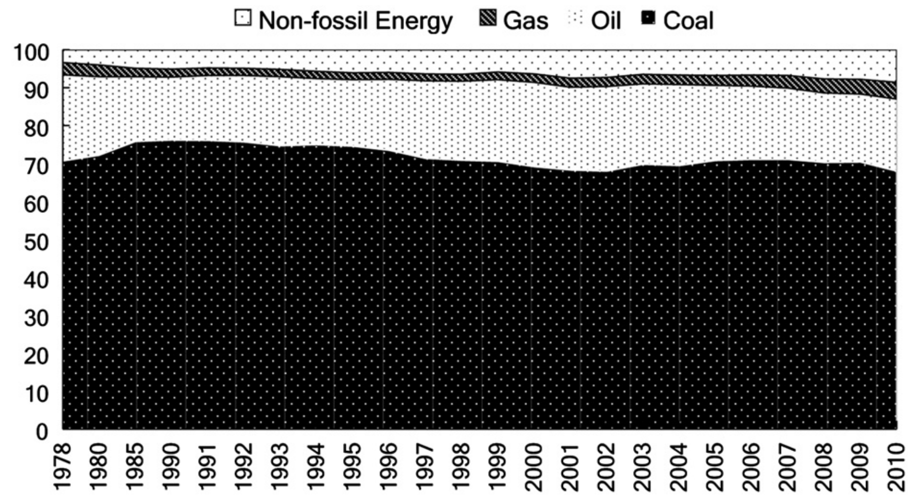

Fig. 1. Primary energy consumption structure of China (1978–2010).

economic advantages and potential compared with solar energy, biomass and other renewable energy.

The past few years witness rapid development in wind power in China. From 2006 to 2010, the installed capacity of wind power had an average annual growth rate of 104%. At the end of 2010, cumulative installed capacity of wind power reached 41.46 million kW. However, given the huge total energy consumption in China, especially the rapid increasing energy demand driven by urbanization and industrialization, the impact of the growth of wind power is not appreciable though; in terms of proportion wind power in primary energy consumption structure remained unchanged, even decreasing slightly.

Factors affecting investment returns of wind power include the following: natural factors such as wind strength and the effective wind time; technical factors like unit installation investment, conversion efficiency from wind energy into electricity, grid accession, etc.; market factors, for example financing costs and coal prices and policy factors, such as tariff levels, land-use policies, and preferential tax policies. Instabilities in these factors magnify investment risk in wind power and consequently make financing the most challenging segment faced by wind power investment. Renewable energy industry development requires enormous amount of funding. According to UNEP, from 2005 to 2009 the world wind power capacity growth rate was 27% and the world wind power generation investment reached 67 billion dollars in 2009 [3]. The global renewable energy investment increases rapidly with huge financing gap. According to the long-term renewable energy development planning, China aims at realizing the goal that the non-fossil energy accounts for 15% of the total energy consumption by 2020. If it is estimated that 29 gigawatt(GW) new wind power will be installed and for each kW comprehensive investment is about 9000 RMB, tentative required investment is about 40 billion dollars.

Wind power development possesses great potential, but exploitation and utilization in scale, and its sustainable development are in need of support from government and a more comprehensive market mechanism. It is thus essential to evaluate the risks and benefits of renewable energy projects, and propose corresponding effective measures to them more attractive for investors. Based on this, this paper aims at solving renewable energy project financing problems and analyzes what impacts renewable energy project development, making collective decisions and raising some proposals from the perspectives of government, investors and environmentalists.

2. Literature review

In the context of renewable energy risk assessment and financing problems, a few scholars and institutions have carried out thorough and systematic research, some of which, home and abroad showed that the following were conducive to renewable energy financing difficulties: lack of start-up funding and necessary technical support, small project scale, high project risk, less investor's interest, and changeful policies [4–6], among which high risk was the major threat for wind power project financing. UNEP [7] suggested that cost in the initial stage of a project was relatively higher; however risk, incomplete information and technical obstacles exist in each phase but investors cannot get the precise project feasibility analysis and risk evaluation. Thus a higher yield is necessary as a compensation for the risk.

According to Pigou's theory, it is advisable for the government to restore the market incentive function by subsidization in the case of positive externalities, so as to make the supply reach the optimal level. Hohmeyer [8] quantified the external benefits embedded in the energy system and analyzed the influence of the external benefits of power tariff within the competitive mode. He pointed out that renewable energy would face serious competitive disadvantages without consideration of external benefits and large-scale wind power development would be delayed for about 15 years. Taking into account the uncertainty of wind speed and the value of clean air, Beenstock [9] calculated the economic benefit of wind power with a set of algorithms. The result showed that wind randomness did not impair the economic value of wind power. Wiser and Pickle [10], Wohlgemuuth and Madlener [11] pointed out that it was because external benefits—such as environmental benefits and social benefits caused by renewable energy project—were ignored that some renewable energy incentive policies were ineffective. Manwell et al. [12] differentiated between the value of utilizing wind power and those of other renewable energies from the perspective of saving fossil energy and reducing pollution emission. Kennedy [13] defined social benefits as saving energy and reducing environmental loss by replacing conventional power with wind power.

At the early stage of wind power development, government support is indispensible to solve wind power project financing difficulties and promote wind power sustainable development. Numerous scholars and institutions put forward a series of measures to improve the profitability and reduce financing risks of wind power projects by means of risk management tools and

policy design [14–17]. Renewable energy incentive policies include Renewable Portfolio System (RPS), Renewable Energy Production Preferential Tax (PTC), Renewable Energy Fuel Standard (RFS), System Benefits Charges (SBC), Tax Examption, and so on.

From the perspective of project financing, Jager and Rathmann [18] estimated how the policies affected the financial benefits of four large-scale renewable power projects. He assessed all the policy tools for renewable power generation technology comprehensively and analyzed the guiding principles for those policies, which involved investment subsidies, credit policy, fiscal policy, and output policy. He found that effective incentive policies can decrease the project cost by 5–10%, and policy combination plan is better than a single scheme. Additionally, it is an important research issue to take the CO_2 emission value into consideration as well when assessing the investment benefit in wind power. Metcalf [19] pointed out that tax revenue of carbon dioxide should not only be used as a compensation for income tax and subsidy for unemployed workers, but also be put into developing and studying renewable energy. WRI (World Resources Institute) [20] proposed that we should promote effective renewable energy standards and reasonably price carbon dioxide by adopting a comprehensive climate and energy scheme to improve the competitiveness of wind power. As for renewable energy risk management, UNEP [21] concluded that insurance products could reduce the risk in renewable energy projects operation so as to improve the project profitability. Mekan [22] carried out feasibility analysis and risk assessment of wind power projects and further conducted sensitivity analysis through stochastic risk models. The results revealed that all the relevant traditional insurance products had a positive effect on the project profitability; especially the default rate was decreased significantly and NPV was thus increased. UNEP and GEF [23] analyzed the positive impacts of wind power derivatives on wind power development and the obstacles it would face.

In China, some studies focus on the related foreign policy and literature review, based on which research people carry out comparative analysis and inductive analysis and give corresponding qualitative financial support policy proposals. Incentive policies largely concentrate on the following policy variables design: (1) reasonable tariff; (2) accelerated depreciation method policy; (3) subsidies following environment levy; (4) general tax credits for power generation corporations and (5) preferential credit policies [24–27].The studies assess the renewable energy project on two aspects—profitability and risk. However the framework of support policy for renewable energy project financing is far from perfect given the following aspects. First, at profitability analysis stage, the above studies merely apply the traditional market pricing models and methods in financial affairs, underestimating the market competitiveness of renewable energy without considering social and environmental benefits. Second, at decision-making stage, the researches stand in the position of the investors while the interests of other participants such as government and environment itself are not fully considered. As for the above problems, this paper introduces the green accounting system into renewable energy project assessment so as to measure economic benefits, environmental benefits and social benefits of renewable energy project thoroughly. Moreover, this article converts the environmental and social benefits into economic value of renewable energy projects in the form of subsidies so as to improve profitability of those projects. Based on this, we employ the Monte Carlo simulation method to identify risk factors, take the variable indexes of the risk factors as policy variables, and with the application of programming solver we put forward a number of feasible policy schemes on the premise that project revenues and earnings are guaranteed. Finally on the basis of the above theoretical project assessment framework we appraise the project that incorporates the above feasible policy schemes and picks the best incentive policy according to assessment results.

The research framework of this paper is as follows. In Section 3 we introduce the research subject, data and methods. In Section 4 we evaluate project profitability by analyzing a case of wind power project, identify the risk factor with the Monte Carlo model and raise the financing incentive policy framework on the basis of the risk factors. Then we propose several feasible supporting policies by the use of programming solver. In Section 5, we work out the best incentive policy from the evaluation results with multiple Criteria analysis model, and reach the conclusions and give our recommendations.

3. Methodology

3.1. Green accounting method

To reflect the advantages held by wind power over thermal power in terms of avoiding fossil energy depletion and environmental pollution, in this paper we introduce the green accounting method, based on which, some adjustments are made for fossil energy consumption costs calculation. The initial storage capacity of fossil energy is s_o, depletion rate is a, then the residual fossil energy resources $q_t = a \times (1-a)^{t-1} \times S_o$. Additionally, we assume that unit output value of fossil energy power is π, the initial cash investment is k, the discount rate is r.

The present value of the project is

$$V_t = \sum_{s=t}^{\infty} \frac{\pi q_s}{(1+r)^{s-t+1}} - K = \sum_{s=t}^{\infty} \frac{\pi a(1-a)^{t-1} S_0}{(1+r)} \left(\frac{1-a}{1+r}\right)^{s-t} - K = \frac{\pi q_t}{a+r} - K \quad (1)$$

According to the green accounting method, resources investment needs to be amortized as the capital cost of resource during the project life cycle, the amortized amount within per unit is

$$\Delta_t = V_t - V_{t+1} = \frac{\pi}{a+r}(q_t - q_{t+1}) = \frac{a}{a+r}\pi q_t \quad (2)$$

The actual revenue of fossil energy generation is

$$\pi q_t - \Delta_t = \pi q_t - \frac{a}{a+r}\pi q_t = \frac{r}{a+r}\pi q_t \quad (3)$$

According to Cairns [28],$a \approx r$, and depletion costs of fossil energy thus is $(1/2)\pi qt$.

We assume that the extra fossil energy consumed by thermal power of the scenario in which there is no renewable resource power generation is taken as an income for the wind power project, and the environment-related tax exemption is also considered as subsidies for the project during its lifecycle.

3.2. Monte Carlo method

In the case that the reliability characteristics of each unit in the system is known but the reliability of the system is too complex to establish accurate mathematical model for prediction, or the models are too complicated to apply, the Monte Carlo simulation method serves as a substitution to approximately calculate the expected value of the reliability of the system. The expected accuracy is to be gradually increased when more simulations are made with the help of software.

3.3. The principle of MCA

MCA techniques are widely used in the analysis and evaluation of multi-target system [29]. In the multi-indicator analysis, we abstract the indexes of an actual project into an n-dimensional

linear matrix. For a particular subject to be analyzed, each index should be given a score by MCA. From the perspective of matrix scope, each specific combination is equivalent to an n-dimensional vector. If there are m kinds of combinations for our selection of the actual situation, this linear space will contain m vectors:

$$\overline{A_1} = (a_{11}, a_{12}, \cdots a_{1n})$$
$$\overline{A_2} = (a_{21}, a_{22}, \cdots a_{2n})$$
$$\ldots$$
$$\overline{A_m} = (a_{m1}, a_{m2}, \cdots a_{mn}) \tag{4}$$

If the importance of all the n indicators in the actual work for the project is the same, that is, the weights of each dimension are equal, we only need to choose vector A with maximum norm ($||\overline{A}||$ is maximum) in this linear space as the best solution of the project. In other words, from the geometric point of view, the selected vector is the longest. In real analysis, sometimes algebraic sum of the vector projection is utilized.

However in reality, the importance of each objective for the project varies. To this end, the weight of each objective needs to be processed to coordinate the priority of each objective. As we have to give weights to each target, the geometric interpretation in space can be construed as such that the weights re-adjust the unit length of each base, thus forming a new n-dimensional linear space. The optimization of each combination in the new space is similar to the foregoing: the vector should be selected with the largest geometric sum (i.e. the norm) of all the components.

In real analysis, we can simply select the vector with the largest algebraic sum, which in this scenario is equivalent to the inner product of each candidate vector and the weight, the size of which represents the optimization degree.

Table 1
Distribution assumption of variables for Monte Carlo simulation.

	Distribution	Characteristic indexes
Long-term interest rate	Standard normal	Mean 5.94%, S.D. 0.59%
Coal price	Standard normal	Mean 550, S.D. 5
CERS price of CO_2 Emission reduction	Standard normal	Mean 15, S.D. 1
Price of electricity	Uniform	Min 0.51, Max 0.61
Depreciation rate	Triangular	Min 6%, Median 8%, Max 16%
Tax rate	Triangular	Min 7%, Median 13%, Max 25%

Note: Uniform Min stands for Minimum, Max stands for Maximum, S.D. stands for Standard Deviation.

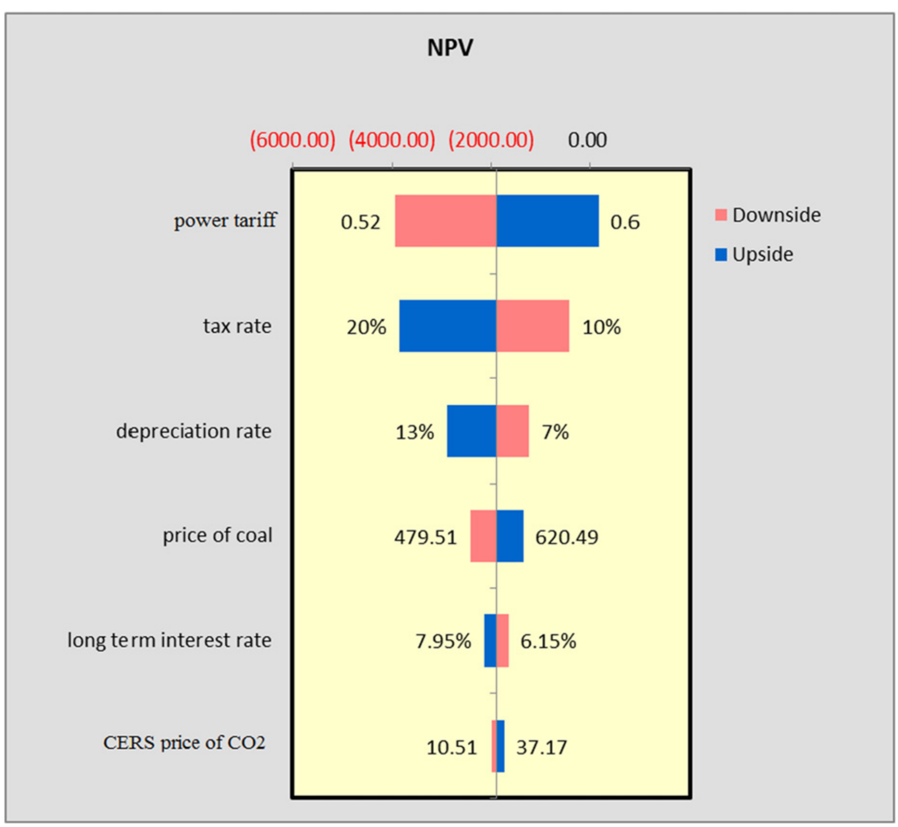

Fig. 2. Sensitivity analysis results of Monte Carlo simulation.

Table 2
Scenario hypothesis of incentive policies.

	Scenario 1	Scenario 2	Scenario 3
Power tariff (RMB/kWh)	0.52–0.54	0.55–0.57	0.58–0.60
Tax rate	18–21%	14–17%	10–13%
Depreciation rate	7–9%	9–11%	11913%
Price of coal (RMB/ton)	479–526	526–573	573–620
Long term interest rate	7.35–7.95%	6.75–7.35%	6.15–6.75%
CERS price of CO_2 (USD/ton)	10.5–19.3	19.4–28.2	28.3–37.1

Note: The US dollar to RMB exchange rate was 7.3 in Dec. 31 2007.

Table 3
Optimal simulation results of the incentive policy.

	Scenario 1	Scenario 2	Scenario 3
Power tariff (RMB/kWh)	0.54	0.57	0.60
Tax rate	21%	17%	13%
Depreciation rate	8%	10%	12%
Price of coal (RMB/ton)	526	573	620
Long term interest rate	7.35%	6.75%	6.15%
CERS price of CO_2 (USD/ton)	14.9	23.8	32.7

Table 4
Monte Carlo simulation results (80% confidential level).

Category	Index	Minimum	Maximum
Environmental benefits	Environment preservation	1553	1562
	Energy reserve	5023	6442
Economic benefits	NPV	0	596.85
	IRR	0%	39%
Social benefits	Debt resource	1870	2445
	Tax	4466	8673
Risk control	Variance of NPV	2097	4458

4. Simulation based on Monte Carlo method

4.1. An analysis of factors influencing wind power investment

According to the previous analysis, the following factors that influence investment returns of the wind power project could be quantified. By observing and calculating 15 years of historical data of the various factors, we assume their distributions and characteristic indexes as shown in Table 1.

4.2. Sensitivity analysis and scenario hypothesis

Under the framework of green accounting, the sensitivities of the wind power investment NPV to all the factors can be derived by the Monte Carlo simulation, which are ranked in Fig. 2. The wind power tariff exerts the greatest impact on NPV, followed successively by tax rate, depreciation rate, coal price, long term interest rate, and CERS price of CO_2. The ranking is pivotal for the government and wind power enterprise in the decision-making process.

With the upside and downside of each factor, we propose Scenario 1, Scenario 2 and Scenario 3 standing for conservative, medium, and radical combinations respectively (Table 2). Subsequently based on the initial parameters of wind power investment and with the object of maximizing NPV, we obtain the optimal parameter results for the three scenarios by the linear optimization method (Table 3).

4.3. The design of supporting policies

Now we work on the effective changing scope of each target variable based on the optimal simulation results in Table 3. Our feasibility analysis on the project consists of the evaluations of economic, social and environmental benefits. In environmental benefits, we adopt several major pollutants emissions covered by pollution tax as indicators. In economic efficiency evaluation, the Net Present Value (NPV) and Internal Rate of Return (IRR) in cash flow analysis model are applied. In social evaluation, we take the tax revenue generated by this project as a positive indicator, the needed loans[1] and subsidies as two negative indicators. Lastly we take the variance of NPV as the risk control index.

According to the distribution characteristics of the various parameters listed above in Table 1, we apply the Monte Carlo simulation method again to obtain the effective changing scope of each target variable, with the results shown in Table 4. The upper and lower limits of each target variable are within 80% confidence interval.

5. Decision with Multiple Criteria Analysis

With the above indexes as decision variables, the initial investment as changing variables, we apply the Multiple Criteria Analysis method to obtain the optimal investment program and scoring matrices.

$$\begin{bmatrix} 5273.51 & 5462.20 & 6008.23 \\ 1741.63 & 1748.25 & 1768.11 \\ 315.90 & 2689.75 & 5389.54 \\ 0.19 & 0.54 & 0.88 \\ 2240.85 & 2086.12 & 1932.70 \\ 5124.02 & 5089.36 & 5049.06 \end{bmatrix}$$

In order to keep the dimension consistent, we employ the following methods to normalize the score matrix.

$$r_{ij} = (\max_j a_{ij} - a_{ij})/(\max_j a_{ij} - \min_j a_{ij}),\ i \in I_2,\ j \in N$$
$$r_{ij} = (a_{ij} - \min_j a_{ij})/(\max_j a_{ij} - \min_j a_{ij}),\ i \in I_2 \& I_3,\ j \in N \tag{5}$$

Standardized score matrix is as follows:

$$\begin{bmatrix} 0.35 & 0.48 & 0.87 \\ 0.13 & 0.15 & 0.21 \\ 0.94 & 1.37 & 1.86 \\ 0.51 & 1.45 & 2.34 \\ 0.37 & 0.63 & 0.89 \\ 0.16 & 0.15 & 0.14 \end{bmatrix}$$

[1] Preferential lending rate and approval policies for wind power facilitate wind power projects successful applications for loans, but the funding pool for loans is limited in scale so the amount of loan funds for wind power projects can be deemed as to an opportunity cost for the entire society.

Table 5
The weights of the Government, investors and environmentalists.

Weights	Government	Investors	Environmentalists
Indicators on economic benefit	1	3	1
Indicators on environmental benefits	2	2	3
Indicators on social benefits	3	1	2

Table 6
Evaluation results of Multiple Criteria Analysis.

Score	Scenario 1	Scenario 2	Scenario 3
Government	3.98	6.41	9.43
Investors	5.84	10.49	15.78
Environmentalists	3.93	6.26	9.48

Three major participants of the wind power market are: government, investors and environmentalists. The government is mostly concerned about social benefits, while investors mostly concerned about economic benefits, and environmentalists emphasize more on environmental benefits. According to the respective benefit orientations of these three groups, we propose the weights of the three categories in Table 5.

So the composite score formula for each program is as follows:

$$R = \sum w_{ij} r_{ij} \tag{6}$$

The running results of this model are shown in Table 6.

According to the above results, evaluation results of the three scenarios by these three participants are identical. Government, investors and environmentalists all give their first ranking to the third scenario, meaning that reasonable and stable return of investment in wind power projects is a must for sustainable development of the industry, and to achieve that policy support and a better market environment are demanded.

Currently wind power tariff in China does not fully reflect the energy substitution effect, environmental and social effects, therefore wind power is disadvantaged due to its higher cost. To take environmental benefits, energy substitution benefits and social benefits into account would absolutely improve investment return dramatically in wind power project. The government should consider the main factors affecting the effectiveness of wind power investment, including depreciation period, tariff, long-term loan rates, coal prices, the CERs price of CO_2 emission reduction, short-term loan rates. Besides, it is another basic key issue for the government on how to balance the relationship between market instruments and policy incentives; consequently concerns from all parties—the government, investors, and environmentalists—about the optimal objectives of wind power development are all determining factors.

Finally, we would like to discuss some ideas as policy suggestions on how to support wind power industry growth in China. First of all, a stable market and policy environment for the wind power industry should be built. In order to meet the needs of the rapid development of the industry, wind power tariff formation mechanism should be further refined in such way that the government focuses mainly on the wind power development and utilization sectors but leaves equipment manufacturing sector to the market. Secondly, technological innovation should be encouraged and promoted to reduce the unit installed cost of wind power. To specify, necessary support should be provided to establish public R&D institutions and test platforms for basic and generic technology R&D, testing and certification in order to solve generic technical problems of the wind power industry. Thirdly, to avoid overcapacity of wind power equipment manufacturing and plan the wind power development with appropriate market-oriented approaches.

Acknowledgment

This topic is a stage research as a result of presiding over the United States Energy Foundation project “Energy subsidy reform and China’s sustainable economic development “in 2011 (Project no. G-1111-15134), Ministry of Education, Philosophy and Social Planning project “Construct renewable energy industry finance risk management and policy support system based on the life cycle theory” in 2012 (Project no. 12YJAZH056), and China Postdoctoral Science Foundation “Sustainable development and social equity: a research based on the theory of energy subsidies and policy practice” in 2009 (Project no. 20090460202). We appreciate the comments of anonymous reviewers, no doubt, any responsibility of this paper lies at our door.

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